A climate and atmosphere simulator for experiments on ecological systems in changing environments

Bruno Verdier, Isabelle Jouanneau, Benoit Simonnet, Christian Rabin, Tom J. M. Van Dooren, Nicolas Delpierre, Jean Clobert, Luc Abbadie, Régis Ferrière & Jean-François Le Galliard

Running title: Climate simulator for environmental science

Supporting Information:

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TABLE S1

Table S1. Size, instruments and general characteristics of the Ecolab. Precision of sensors are those provided by the manufacturer.

General characteristics	
Dimensions	Climate chamber: 13 m^3 (working space: 5 m^2 on the ground and 2.2 m height) Optional circular stainless steel lysimeter: 1m^3, 1.3 m^2 and 80 cm height Optional temperature-regulated table: 1.3 m × 1.3 m
Confinement	Closed and controlled environment facility Lysimeter for aquatic and terrestrial ecosystems
Atmospheric climate control	
Temperatures	-13°C to +47°C Independent temperature control of the lysimeter in 3 layers Independent temperature control of the table at the bottom
Humidity	0.8 g water per kg air (-8°C) to 113 g/kg (50°C) equivalent to a range of 7-100 %
Rainfall	Variable droplet size (under test), adjustable water quantity and quality
Lighting	Optional modular LED-lighting (max.: 400 $W.m^{-2}$) and other technologies on demand Include a rotation-translation system for homogenization
Pressure	Uncontrolled (± 1000 Pa) or strictly controlled (under test)
Atmospheric gas control	
CO_2	50-20,000 ppm (injection and absorption controlled by mass flow meters)
O_2	4000-210,000 ppm (downward control, substitution with N_2)
Available instrumentation	
Lysimeter	Weight: Sartorius gauge PR 6241; Temperature: Pt100 probes (± 0.1 °C)
Atmosphere	Temperature: Pt100 probes (± 0.1°C) Humidity: capacitive sensor (Rotronic HF53/46 HC-S, ± 0.8%HR, ±0.1K at 23°C ±5°C) Humidity: psychrometer Ahlborn FNA 846 (0-60 °C, 10-100 %RH, ± 0.1 %HR at 25°C) CO_2 concentration: LICOR LI-820 with home-made autocalibration and mass flow meter O_2 concentration: CTX 300 (Oldham, imprecision ±1.5% of entire scale between 0-30%) Other gases (N_2, CH_4): micro-gas chromatograph CP-4900 (Varian Inc.) Pressure: JUMO 40 transmitter (950-1050 mbar; imprecision ≤0.05% between 10-50°C Rainfall: laser disdrometer (Thies Clima)
Light	Irradiance: Pyranometer SP-214 (Apogee, 350-1100 nm, 0-1250 $W.m^2$ ± 1%) Light spectrum: Ocean optics JAZ, 200-1100nm.
Study systems	
Plants	Small vascular plants up to 30-60 cm high above ground
Animals	Small animals including insects or fishes
Communities	Aquatic and terrestrial communities including soil-plant compartments

FIGURE S1

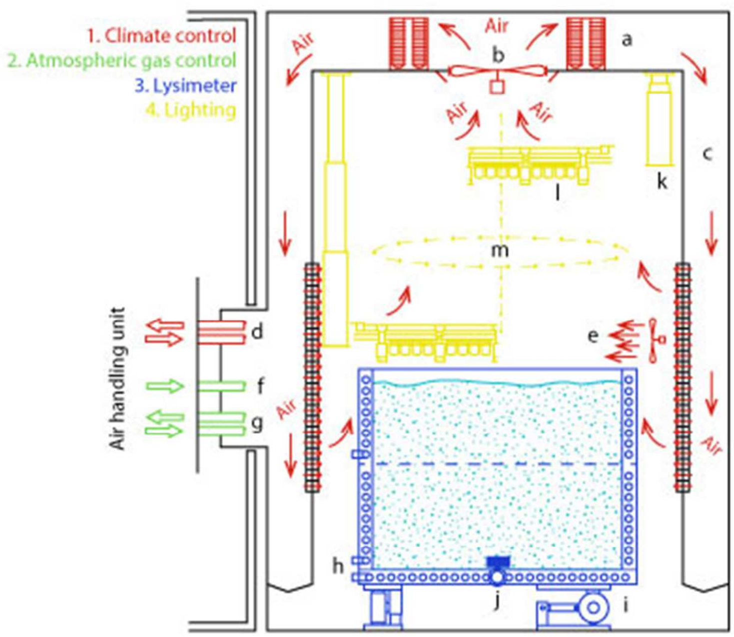


Diagram showing the main functional groups of equipment controlling the environment inside a climate chamber. 1 - Climate control functions including (a) a cold-heat exchanger for regulating air temperature and participating in air drying, (b) the main fan, (c) a plenum space to homogenise airflow, (d) the air humidification circuit, and (e) forced ventilation. 2 - The atmospheric gas control functions including (f) a system of controlled gas injection and (g) a circuit of CO_2 absorption. 3 – The lysimeter functions with (h) distribution of warm and cold fluids in three independent exchangers, (i) three strain gauges for weight measurement, and (j) a programmable electromechanical drain. 4 – The lighting system functions comprising (k) columns mounted on telescopic cylinders, (l) optional LED lighting devices, and (m) a rotation and translation device to homogenize light quantity intercepted by the ecosystem.

APPENDIX S1 – ACCURACY OF CLIMATE REGULATION

Results of climate regulation at constant values

At -10°C, the bias (also called trueness) of temperature control is +0.23°C (measured temperature slightly higher than the set-point) and the imprecision reaches ± 0.06°C giving an accuracy of ± 0.25°C. Between 0°C and 40°C, the bias of the temperature control depends significantly on set-point values (ANOVA linear model using generalized least squares, $F_{12, 22\,389} = 8.20$, $P < 0.0001$) but is generally very close to zero (Table S2, averaging -0.01°C). The imprecision equals on average ± 0.26°C (Table S2, mean accuracy = 0.26°C). Bias shifts from positive to negative values when the set-point for temperature increases. The relative humidity is regulated between 0°C and 40°C, but the control is not efficient for a set-point of 0°C (Table S2). For positive temperatures, bias for the relative humidity control depends significantly on set-point values (ANOVA linear model using generalized least squares, $F_{9, 17977} = 3295.2$, $P < 0.0001$) but is generally very low (mean=-1.16%) while the imprecision is low (Table S2, ± 2.4 % on average; mean accuracy = 2.68 %). The inaccuracy of humidity regulation increases when the set-point for humidity is higher and when the set-point for air temperature is lower. This is most probably the consequence of the fact that relative humidity is more sensitive to slight changes in air water content at low temperature and humidity sensors at more inaccurate when air humidity increases.

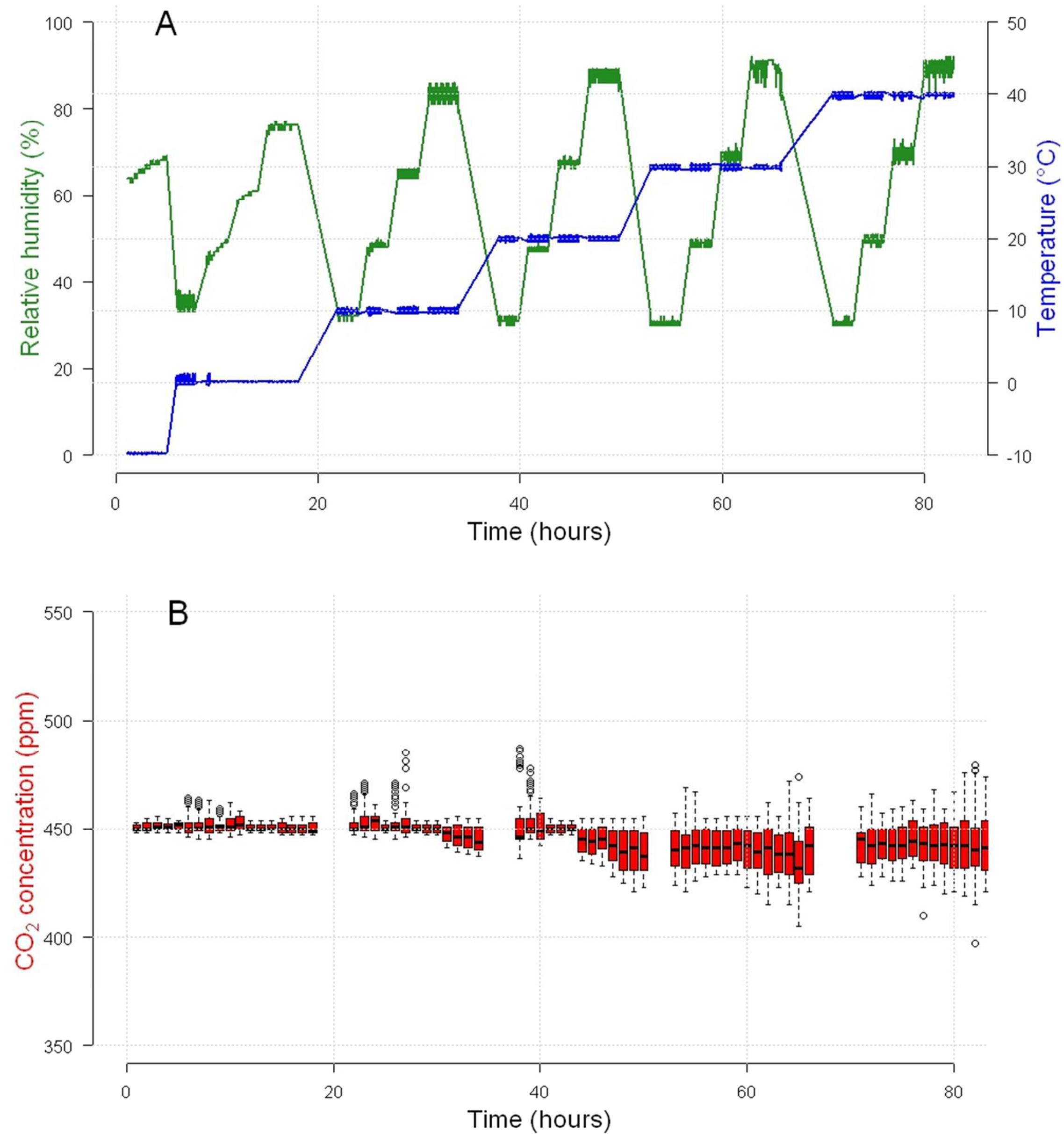


Figure S2. Changes in temperature, relative humidity (A) and atmospheric CO_2 concentration (B) during a stepwise simulation of constant environments. In this simulation, the bias for CO_2 concentration is -3.9 ppm, the imprecision is ± 9 ppm and the accuracy (mean squared error) is thus ± 9.9 ppm. The quality of the CO_2 control decreases as the air is charged with water. The time is indicated in hours.

Conditions	30 %	50 %	70 %	90 %
0°C	0.17 ± 0.41 °C [0.44] 5.08 ± 1.13 % [5.21]	0.15 ± 0.23 °C [0.27] -2.83 ± 1.47 % [3.19]	0.11 ± 0.06 °C [0.13] -9.95 ± 0.84 % [9.99]	0.11 ± 0.05 °C [0.13] -14.11 ± 0.40 % [14.2]
10°C	-0.04 ± 0.25 °C [0.24] 2.47 ± 0.79 % [2.38]	-0.02 ± 0.26 °C [0.26] -1.70 ± 0.72 % [1.84]	0.06 ± 0.33 °C [0.34] -5.29 ± 0.78 % [5.34]	0.06 ± 0.28 °C [0.28] -6.71 ± 1.53 % [6.82]
20°C	-0.06 ± 0.19 °C [0.20] 1.41 ± 0.83 % [1.28]	0.04 ± 0.30 °C [0.30] -2.29 ± 0.47 % [2.34]	0.03 ± 0.28 °C [0.29] -2.67 ± 0.52 % [2.72]	0.01 ± 0.22 °C [0.23] -2.51 ± 1.08 % [2.73]
30°C	-0.08 ± 0.22 °C [0.23] 0.68 ± 0.52 % [0.84]	-0.08 ± 0.28 °C [0.29] -1.07 ± 0.52 % [1.20]	-0.06± 0.25 °C [0.26] -0.92 ± 1.01 % [1.36]	-0.07 ± 0.18 °C [0.18] -0.66 ± 1.93 % [1.80]
40°C	-0.12 ± 0.23 °C [0.30] 0.60 ± 0.55 % [0.85]	-0.12 ± 0.24 [0.28] -0.24 ± 0.73 % [0.77]	-0.13 ± 0.20 [0.24] -0.01 ± 1.15 % [1.14]	-0.11 ± 0.16 [0.19] -0.15 ± 1.36 % [1.33]

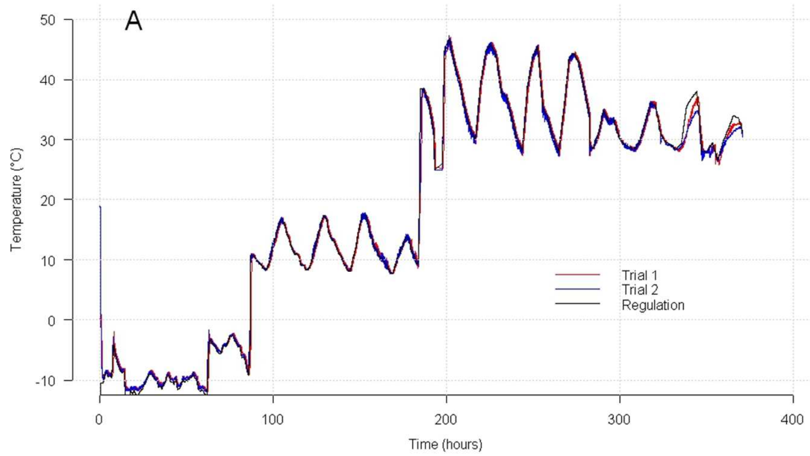
Table S2. Trueness (bias) ± imprecision (sampling standard deviation) of climate regulation in a constant environment for temperature (°C) and relative humidity (%). Accuracy (square root of the mean squared error) is provided in brackets.

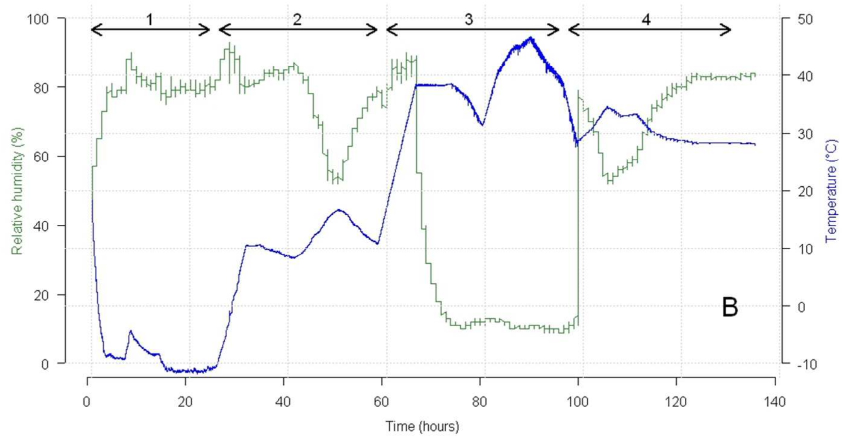
Results of climate regulation in variable climates

Bias and dispersion values for temperature control are generally low, except for the tropical climate that requires a strong production of both heat and moisture (Table S3, differences in bias between climate types: ANOVA linear model using generalized least squares, $F_{4, 213781}$ = 3295.2, P < 0.0001). The bias is positive for cold climates and negative for hot climates, while imprecision value is typically less than ± 0.30 ° C. In general, accuracy is very high (e.g., temperature: mean bias = 0.11°C, mean imprecision = 0.55°C).

	Climate type	**1**	**2**	**3**	**4**	**5**
Mean	**Temperature**	-8.16 ± 2.94	11.6 ± 2.68	37.5 ± 5.33	38.2 ± 5.32	30.8 ± 2.51
	Relative humidity	72.3 ± 3.7	68.9 ± 11.7	43.8 ± 5.46	12.6 ± 1.9	71.1 ± 11.8
	Specific humidity	1.54 ± 0.46	5.82 ± 0.74	19.33 ± 7.20	5.48 ± 1.66	20.1 ± 0.99
Bias and imprecision	**Temperature**	0.52 ± 0.30	0.02 ± 0.18	-0.14 ± 0.31	-0.16 ± 0.29	-0.49 ± 0.72
	Relative humidity	Not controlled	-0.68 ± 4.45	31.9 ± 5.77	0.73 ± 1.13	3.28 ± 3.07
	Specific humidity	Not controlled	-0.004 ± 0.35	14.31 ± 5.89	0.27 ± 0.47	0.50 ± 0.62
Accuracy	**Temperature**	0.60	0.18	0.34	0.33	0.87
	Relative humidity	Not controlled	4.50	32.45	1.35	4.49
	Specific humidity	Not controlled	0.35	15.48	0.54	0.79

Table S3. Trueness (bias) ± imprecision and accuracy of climate regulation in variable environments for temperature (°C), relative humidity (%) and specific humidity (g of water vapour per kg dry air). See figure 2B for the description of climate types.





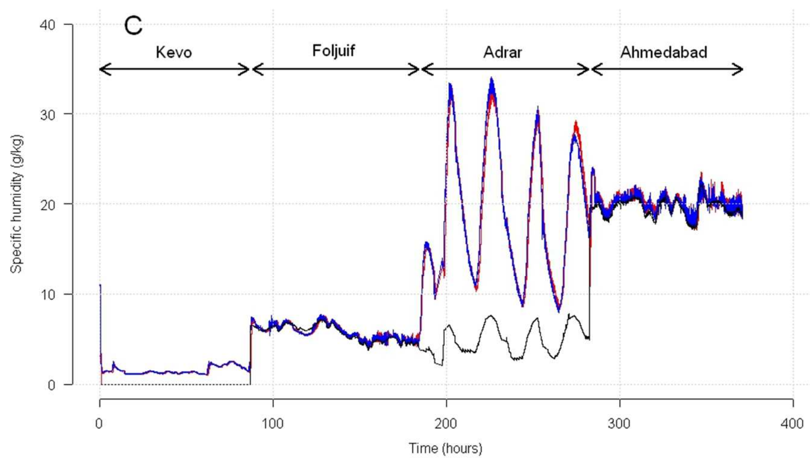


Figure S3. Temperature (A), relative humidity (B) and specific humidity (C) during two independent repetitions of the same simulation of four climate types. Data are recorded values (red and blue curves) and pre-defined set-points (black curve).

Climate type	1	2	3	5
Temperature	0.963 [0.962,0.965]	0.980 [0.979,0.981]	0.968 [0.967,0.970]	0.948 [0.946,0.950]
Relative humidity	Not controlled	0.971 [0.970,0.972]	0.968 [0.967,0.969]	0.958 [0.956,0.960]
Specific humidity	Not controlled	0.957 [0.955,0.959]	0.979 [0.978,0.980]	0.826 [0.819,0.833]

Table S4. Spearman correlation coefficient (mean and confidence interval) between the two runs for each of the four climates.

APPENDIX S2 – ACCURACY OF CO_2 REGULATION

The bias and imprecision values are low (Table S5) with an average bias of 0.7 ppm and an average imprecision of ± 2.8 ppm. The bias, however small, varies significantly depending on climatic conditions and on the CO_2 set-point (ANOVA linear model using generalized least squares, $F_{12, 18745} = 36.6.$, $P < 0.0001$, see Figure S4). Under the conditions of this experiment, bias is negative for a set-point of 500 ppm (mean ranges from -0.5 to -0.8 ppm) and positive in other cases through a maximum reached at the set-point of 400 ppm especially in climates 1 and 2. These values are very small relative to relevant effects on living organisms and average daily fluctuations.

Conditions	**1**	**2**	**3**	**4**
200 ppm	0.19 ± 2.04 ppm [2.05 ppm]	0.72 ± 2.45 ppm [2.55 ppm]	1.89 ± 2.77 ppm [3.35 ppm]	0.40 ± 3.56 ppm [3.58 ppm]
300 ppm	0.91 ± 2.48 ppm [2.64 ppm]	0.45 ± 3.35 ppm [3.39 ppm]	0.66 ± 3.13 ppm [3.20 ppm]	0.62 ± 3.79 ppm [3.84 ppm]
380 ppm	1.79 ± 2.01 ppm [2.69 ppm]	1.32 ± 2.05 ppm [2.44 ppm]	1.00 ± 2.90 ppm [3.07 ppm]	0.66 ± 2.78 ppm [2.86 ppm]
400 ppm	2.09 ± 1.55 ppm [2.61 ppm]	1.48 ± 2.81 ppm [3.17 ppm]	0.77 ± 3.25 ppm [3.35 ppm]	1.19 ± 3.06 ppm [3.28 ppm]
500 ppm	-0.76 ± 1.30 ppm [1.51 ppm]	-0.52 ± 2.22 ppm [2.28 ppm]	-0.64 ± 2.21 ppm [2.30 ppm]	0.44 ± 1.59 ppm [1.65 ppm]

Table S5. Trueness (bias) ± imprecision (sampling standard deviation) for CO_2 concentration (ppm) in variable environments according to climate types and CO_2 set-points. See Figure 3 in the main text for the description of climate types. Accuracy (square root of the mean squared error) is provided in brackets.

APPENDIX S3 – REGULATION OF THERMAL GRADIENT

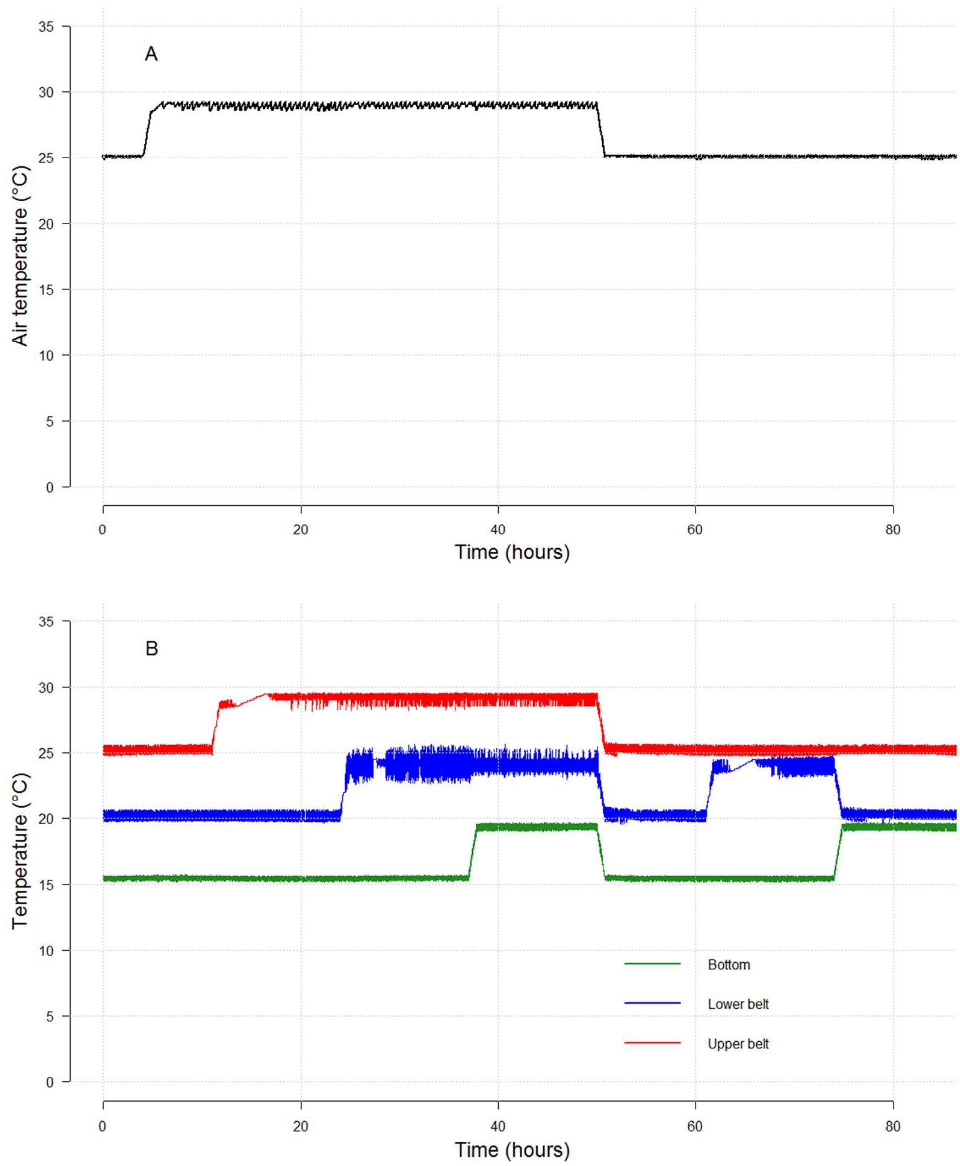


Figure S4. Temperature records in the atmosphere of the chamber (A) and in the bottom and two belts of the lysimeter filled with a 75 cm deep freshwater column (B). The starting conditions imposed a thermal gradient typical of lakes during warm summer days in temperate climate zones. Temperature set-points were increased by +4°C in the chamber and each component of the lysimeter temperature regulation to simulate climate warming predicted over the next century. Variance around the mean in panel B is caused by cold-water fluid circulation in the 3-way valve allowing thermal regulation in each component of the lysimeter and where temperature is recorded.

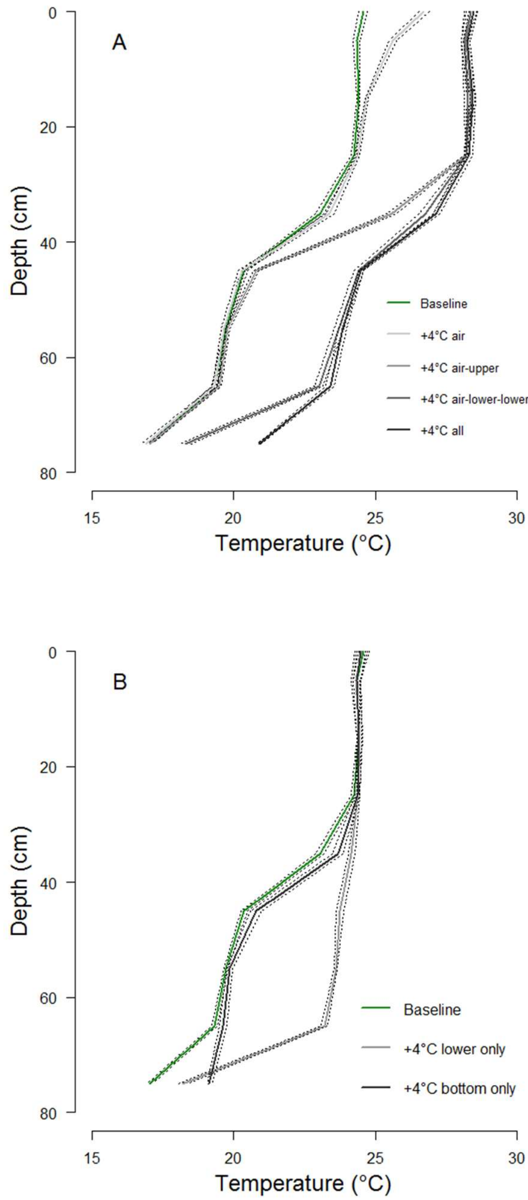


Figure S5. Thermal gradient at equilibrium (colored curves) and confidence intervals (dotted curves) measured by thermal probes installed at water surface and every 10 cm from 5 cm deep to the bottom of the lysimeter (sediment layer). A. Simulation of a +4°C increase in the temperature set-points of the chamber, of the chamber and the upper belt of the lysimeter, of the chamber and the lower-upper belts of the lysimeter and of the chamber and all components of the lysimeter. B. Simulation of a +4°C increase in the temperature set-points of the lower belt and of the bottom of the lysimeter.